USING HELP MODEL FOR DESIGNING GEOCOMPOSITE DRAINAGE SYSTEMS IN LANDFILLS

GHADA ELLITHY, PH.D., TENAX CORPORATION
UNITED STATES OF AMERICA
AIGEN ZHAO, PH.D., P.E., TENAX CORPORATION
UNITED STATES OF AMERICA

ABSTRACT

The US EPA's HELP (Hydraulic Evaluation of Landfill Performance) model is by far the most used tool for analyzing water balance in landfill lining and capping systems. However, a proper simulation of geocomposite lateral drainage layers in the HELP Model is not well established. A misinterpretation of the model's output results can lead to an unsafe design of the drainage systems in landfills. A parametric study was conducted to show the importance of using measured geocomposite properties -versus default ones- as input values and their effect on the estimated amount of lateral drainage and the head on the liner as presented in the model's output. It was demonstrated that the maximum head on the liner, as calculated by McEnroe's equation, is valid only when it lies within the thickness of the geocomposite. A design example is presented to demonstrate the proper use and interpretation of HELP model input and output data. Also, the effect of incorporating updated weather data was investigated.

INTRODUCTION

The use of geonets, and geocomposites (geonets with laminated geotextile on one or both sides) as drainage layers in landfills to replace soil drainage layers, was introduced to save space and simplify construction on slopes. Also, when soil drainage layer materials are not readily available, geosynthetics provide a viable alternative. However, design methodologies of geosynthetics drainage systems, based on the HELP model output, are not well established.

Figure 1 shows a typical cross section in a landfill. There are two main functions of a lateral drainage layer in a cover system: 1) to reduce the seepage forces in the overlying soil layer to increase the factor of safety with regard to slope stability, and 2) to reduce the head on top of the GCL, geomembrane or compacted clay liner.

The flow capacity in a drainage geonet or geocomposite is highly dependent on the applied load, hydraulic gradient and the seating period. The hydraulic conductivity of a soil drainage layer is relatively constant under the practical ranges of normal loads encountered in such applications. Also, the flow rate in drainage geonets or geocomposites is not linearly proportional to the hydraulic gradient. This indicates a non-Darcian flow at higher hydraulic gradients. Geosynthetics are made of polymeric materials that tend to creep with time. Additionally, the structure of the geonet plays a role in the level of that creep. Other factors such as geotextile/ soil intrusion, chemical and biological degradation reduce the flow capacity of geosynthetic drainage materials. All these factors indicate the importance of considering the difference between geosynthetics and typical soil drainage materials in design.

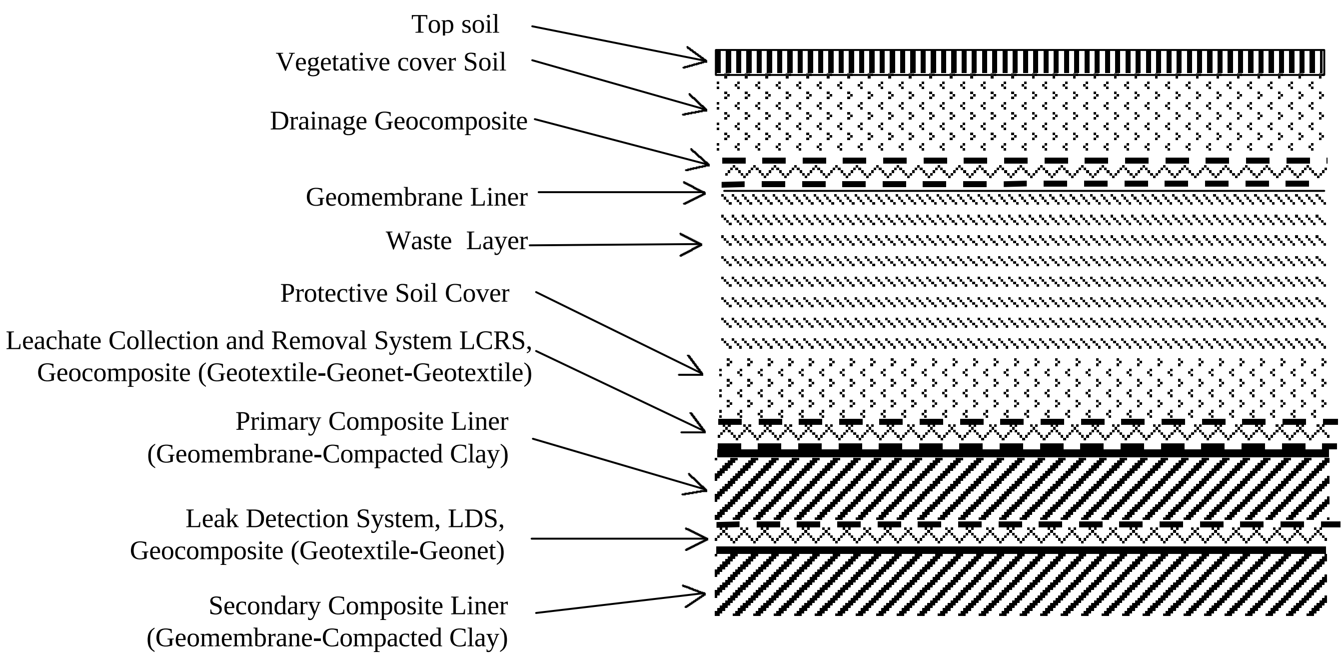

Figure 1: Typical Cross Section in a Landfill

In this paper, the input data for the HELP model for a geosynthetics drainage layer are reviewed, including geometric and hydraulic properties. A parametric study is conducted on a typical landfill cover cross-section to show the effect of using geocomposite properties measured under simulated field conditions as an input compared to the default values. The results are presented in terms of the estimated amount of lateral drainage and the head on the liner as shown in the HELP Model output. The validity of using the maximum head on the liner, as calculated by McEnroe's equation, McEnroe, 1993, is also discussed.

A design example is presented to demonstrate the proper use and interpretation of HELP model input and output data. The effect of incorporating updated weather data in the simulations compared to the historic weather data used by the HELP Model will also be investigated.

THE HELP MODEL

The HELP model is a quasi –two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil and design data and uses solution techniques that account for more than ten above-surface and subsurface hydraulic processes including precipitation, snowfall, runoff, and evapotranspiration. The three main weather data required for the HELP model are: precipitation, temperature, and solar radiation.

The HELP model supports three types of soil layers;1) a vertical percolation layer, e.g. the waste layer, in which the downward flow is modeled by unsaturated vertical gravity drainage, and the upward flow due to evapotranspiration by an extraction. 2) A lateral drainage layer, e.g. LDS layer, to conduct drainage laterally to a collection and removal system. The lateral flow in this layer is modeled as saturated flow. 3) A barrier soil liner to restrict vertical leakage or percolation in which a saturated vertical flow is allowed. The liner soil layer is assumed to be saturated all the time, which means that all the percolation through it will be considered leakage.

The following are input data required by the HELP model to simulate a lateral drainage layer:

- Layer Thickness (cm)
- Moisture Retention Parameters:
  - Porosity (vol/vol), the ratio of active pore volume to the total volume
  - Field Capacity (vol/vol), the maximum volumetric water content that does not result in gravity drainage.
  - Wilting Point (vol/vol), the lowest volumetric water content that can be achieved by plant transpiration
- Saturated hydraulic conductivity (cm/sec)
- Max Drainage Length (m), the horizontal projection of the slope
- Drain Slope (%), from 0 to 50%

It’s very important to note that all dimensional and hydraulic input data for a geosynthetic drainage layer should be specified under the anticipated field conditions. Therefore, for a particular geosynthetic drainage layer, measured values of thickness, porosity, and saturated hydraulic conductivity are used in the parametric study. Field Capacity, and Wilting Point apply more to soils. For geosynthetic materials, the two properties are not well defined values. Default values, as suggested in the HELP model, of 0.01 and 0.005 respectively, will be used in the parametric study.

PARAMETRIC STUDY

Slopes in landfill final closure systems are among the largest man-made slopes. Careful design considerations need to be taken to ensure both hydraulic and mechanical stability. Several cases have been reported of landfill capping systems that failed due to an inadequate flow capacity of the drainage systems, Soong and Koerner, 1994. Figure 2 shows a cross section of the flat slope in a typical landfill cap profile which consists of a cover soil, geocomposite lateral drainage layer and a geomembrane liner. The slope is assumed to be 3% and 33% (1.7^o, 18.4^o) with a horizontal length of 40 m (131 ft). The hydraulic conductivity of the cover soil was assumed within a typical range of a vegetative support layer. Bare (no vegetation) and no surface runoff were modeled. Table 1 shows the relevant properties of the three layers.

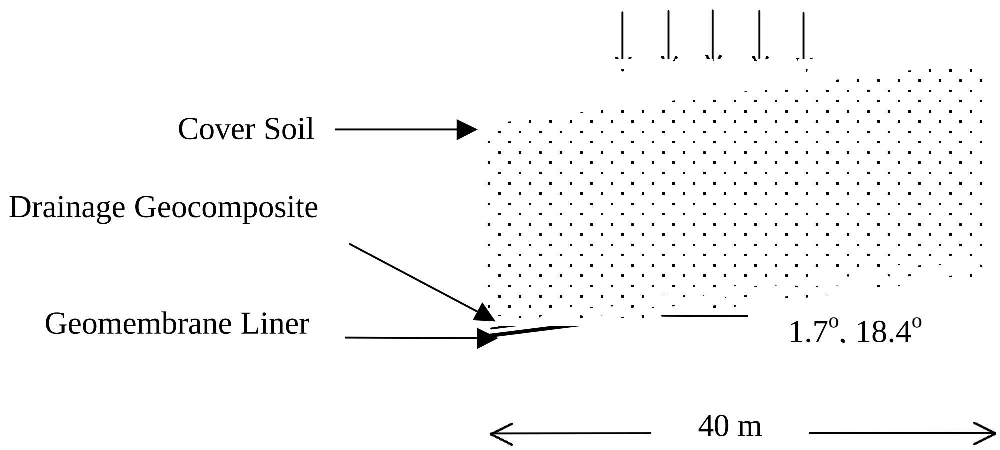

Figure 2: Landfill Cover System Example

Table 1: Layer Properties

Layer	Thickness (cm)	Saturated Hydraulic Conductivity (cm/sec)	Moisture Retention Parameters (vol/vol)		
			Porosity	Field Capacity	Wilting Point
Cover Soil	45.00	$1.0 \times 10^{-5} – 1.0 \times 10^{-3}$	0.40	0.15	0.01
Drainage Geocomposite	0.50 – 0.75	1.0×10^{1} - 5.0×10^{1}	0.85	0.01	0.005
Geomembrane Liner	0.15	2×10^{-13}	-	-	-

The parametric study was conducted to evaluate the effect of the variation in the saturated hydraulic conductivity of the cover soil on the collected lateral drainage and maximum head on the liner calculated by McEnroe's equation and as presented in the HELP model output. The precipitation minus runoff, evapotranspiration, and moisture storage change will infiltrate into the lateral drainage system. The drainage collected from the lateral drainage layer, as calculated by the HELP model, is the difference between the vertical percolation from the layer directly above and the leakage from the liner. For the purpose of this parametric study, the geomembrane liner is modeled with no pinholes or installation defects to minimize the leakage through it. This maximizes the lateral drainage collected and hence the head on top of the liner for a given infiltration rate.

Each case was run for a simulated period of time of one year, based on the default precipitation, temperatures, and solar radiation weather data of Baltimore, Maryland. Two drainage geocomposites GC1 and GC2 were considered with thickness and hydraulic conductivity of 0.5 cm, 10 cm/sec and 0.75 cm, 50 cm/sec respectively. GC1 is a default geocomposite in the HELP model. The results presented are from the “Peak Daily” summary table of the HELP model output. The data in this table don’t necessarily correspond to a single day from the analysis period of time. For example, the peak daily drainage collected might not be on the same day as the peak daily precipitation, because on the day of the peak precipitation, a high level of runoff might take place that reduces the amount of infiltration into the sub-layers, hence reducing the amount of collected lateral drainage. For that reason, a water- balance analysis shouldn’t be conducted by subtracting the “Runoff” value from the “Precipitation” value as presented in the “Peak Daily” summary table.

Flat Slopes

Figure 3 shows the effect of changing the hydraulic conductivity of the cover soil on both the amount of lateral drainage collected from the geocomposites (thin lines), and the maximum. head on the liner (thick lines). Both drainage geocomposites GC1 and GC2 seem to have an adequate flow capacity until a point close to an infiltration rate of 30 mm/day. Here, the flow capacity of GC1 starts to be exceeded and the head on the liner is higher than GC1 thickness. Up to this point, the lateral drainage collected from both geocomposites is approximately equal. Beyond this point, GC1 becomes saturated, and the head on the liner and the amount of lateral drainage of GC1 increase significantly. However, these values lack accuracy as will be explained below. The infiltration rate that will saturate GC1 at the toe section of the 40 m slope, can be estimated as follows:

Infiltration rate = thickness x hydraulic conductivity x gradient / slope length
= 0.5 cm x 10 cm/sec x 0.03 / 4000 cm = $3.75\text{x}10^{-5}$ cm/sec (32.4 mm/day)

For GC2, the saturation infiltration rate is estimated at $1.48\text{x}10^{-4}$ cm/sec or 128.3 mm/day. At approximately 32.4 mm/day of infiltration into the drainage layer, the head on the liner in GC1 dramatically increases and exceeds the thickness of the geocomposite. In the case of GC2, the

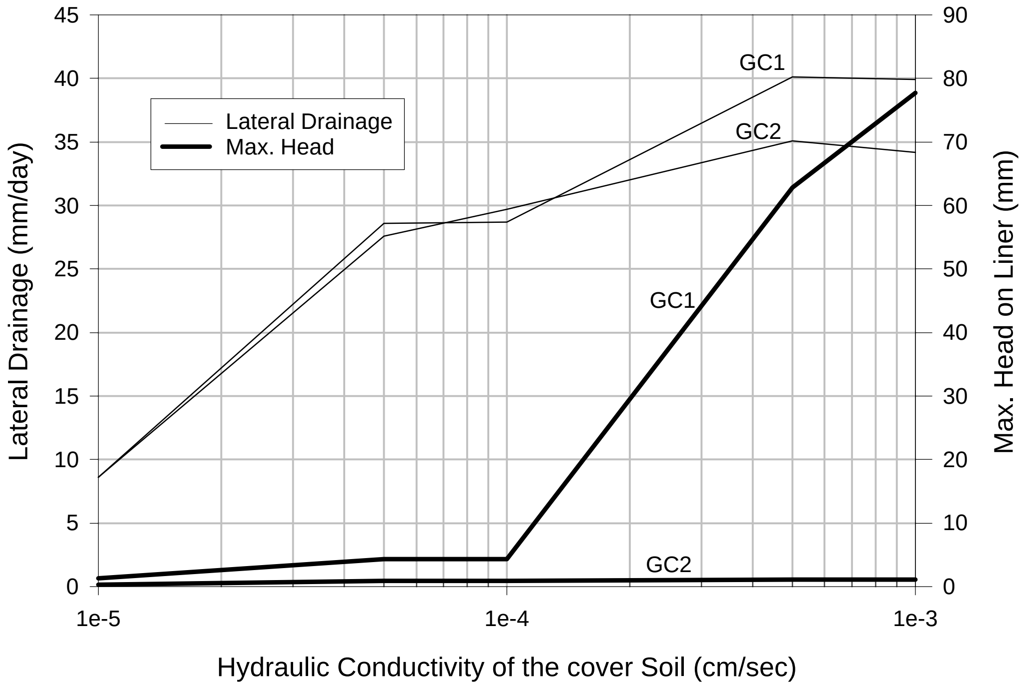

Figure 3: Effect of Cover Soil Hydraulic Conductivity on Lateral Drainage and Max. Head, Default Precipitation Data, Slope; 3%

maximum head on the liner stays within the thickness over the selected range of cover soil hydraulic conductivities, since it requires a higher value of infiltration rate to saturate.

The default maximum daily precipitation rate for this particular location is 76.4 mm/day (8.8 x 10^{-5} cm/sec). A lateral drainage of approximately 40 mm/day is the maximum daily precipitation minus evapotranspiration. When the lateral drainage system is saturated and the head above the liner extends into more than one layer as in case of GC1, the HELP model assigns a weight- averaged saturated hydraulic conductivity of the saturated zone. This is based on the ratio of the head in the layers and has a value that lies between the high value of the drainage layer, and the lower value of the cover soil. This weighted value is used in calculating the maximum head with McEnroe's equation. Back calculating this value in the case of GC1 and a maximum head of 77 mm, a value of approximately 0.15 cm/sec is estimated. This value lies between 10 cm/sec for GC1 and $1x10^{-3}$cm/sec for the cover soil.

It's the authors opinion that such a weighted hydraulic conductivity for the saturated zone is only valid when using a soil drainage layer and only when its hydraulic conductivity is within one or two orders of magnitude of the cover soil's. In such cases, the weighted hydraulic conductivity could be a representative value of the continuous vertical movement of the water between the cover soil and the lateral drainage layer. However in the case of using a geocomposite as a drainage layer, where its hydraulic conductivity could be as high as 5 orders of magnitude higher than that of the cover soil, it's unlikely that the water movement is going to be continuous between the two layers, and it's going to be drained immediately through the geocomposite. Assigning a weight-averaged hydraulic conductivity for such a system will tend to significantly underestimate the head over the liner.

Side Slopes

For the configuration in Figure 2, the same parametric study has been conducted on a slope of 3H: 1V slope (18.4^o) and a hypothetical weather pattern with high daily precipitation rates manually input into the HELP model to ensure a fully saturated condition of the cover soil. The maximum impingement rate is the lowest saturated hydraulic conductivity of the sub-profile layers above the liner, or the infiltration rate whichever is lower. So in this case the hydraulic conductivity of the cover soil is the controlling factor on the amount of the collected lateral drainage.

Figure 4 shows the lateral drainage amount collected from geocomposites GC1 and GC2 (thin lines), and the max. head on the liner (thick lines). A direct relationship between the amount of lateral drainage and the cover soil hydraulic conductivity exists when that layer is fully saturated and the flow capacity of the drainage layer is adequate to drain away the infiltrated water. At a hydraulic conductivity of $1x10^{-4}$ cm/sec, a drainage amount of 86.4 mm/day was collected from both GC1 and GC2 since their flow capacity of $4.1x10^{-4}$ cm/sec and $3.1x10^{-3}$ cm/sec respectively, wasn't exceeded. When the hydraulic conductivity of the cover soil is increased to $1x10^{-3}$ cm/sec, the flow capacity of GC2 is still not exceeded, and the head over the liner is kept within the thickness of the geocomposites. Here again, the amount of the lateral drainage corresponds to the maximum impingement rate. However, with GC1, the resulting head of approximately 800 mm exceeds the thickness of the cover soil, therefore the lateral drainage is not correct.

For the design of a geocomposite lateral drainage system, the head over the liner, as shown in the peak daily summary table, should not exceed the thickness of the geocomposite. If the resulting maximum head, as calculated by McEnroe's equation, exceeds the thickness of the geocomposite, neither its value nor the lateral drainage amount are correct values. Another geocomposite material with higher performance values should be considered and the simulation repeated until the resulting maximum head is within the thickness of the geocomposite.

UPDATED WEATHER DATA

The default weather data stored in the HELP model are for the five years from 1974 to 1978. All synthetically generated weather data for the analysis period years are based on the statistical seasonal patterns of those five years. The HELP model accepts different formats of user input

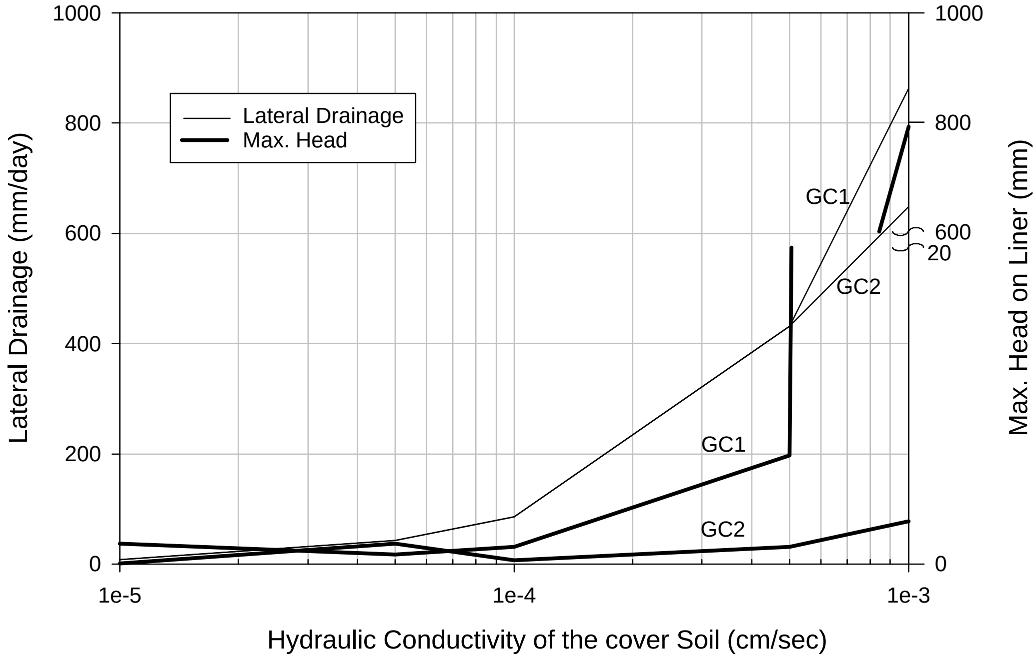

Figure 4: Effect of Cover Soil Hydraulic Conductivity on Lateral Drainage and Max. Head, Hypothetical Precipitation Data, Slope; 33%

from weather data files such as NOAA, ASCII, and Canadian Climatological. In recent years climatical changes have occurred due to some phenomena such as El Ninio, resulting in an increase in the precipitation rates above the reported averages nation wide.

On the National Oceanic Agency (NOAA) web site on the Internet; http://www.nndc.noaa.gov/ temperature, and precipitation data are available for most of the weather stations in the nation for a nominal price. However, more effort is required to make these weather data files compatible with the HELP model. For the purpose of this study, precipitation data from January 1999 to December 1999 for Baltimore, Maryland were manually input into the HELP model and the previous simulations were run for the 3% slope and GC1.

Figure 5 shows the effect of using updated precipitation data on both the maximum head on the liner and the amount of lateral drainage. The data of 1999 show a maximum daily precipitation of 127.5 mm/ day corresponding to only 76.4 mm/day from the historic data used by the HELP model. At a hydraulic conductivity of $1x10^{-4}$ cm/sec for the cover soil, the GC1 geocomposite is no longer capable of providing enough flow capacity, and the maximum head on the liner far exceeds the thickness of the geocomposite. Thus, another geocomposite with higher flow capacity should be considered.

The HELP model precipitation data is based on an average daily rate. This may not be as critical as considering a 6 hour average, as noted by Soong and Koerner, i.e., within a few hours during a storm event, the cover soil could be saturated. This may not be simulated if the storm event is reported on a daily average.

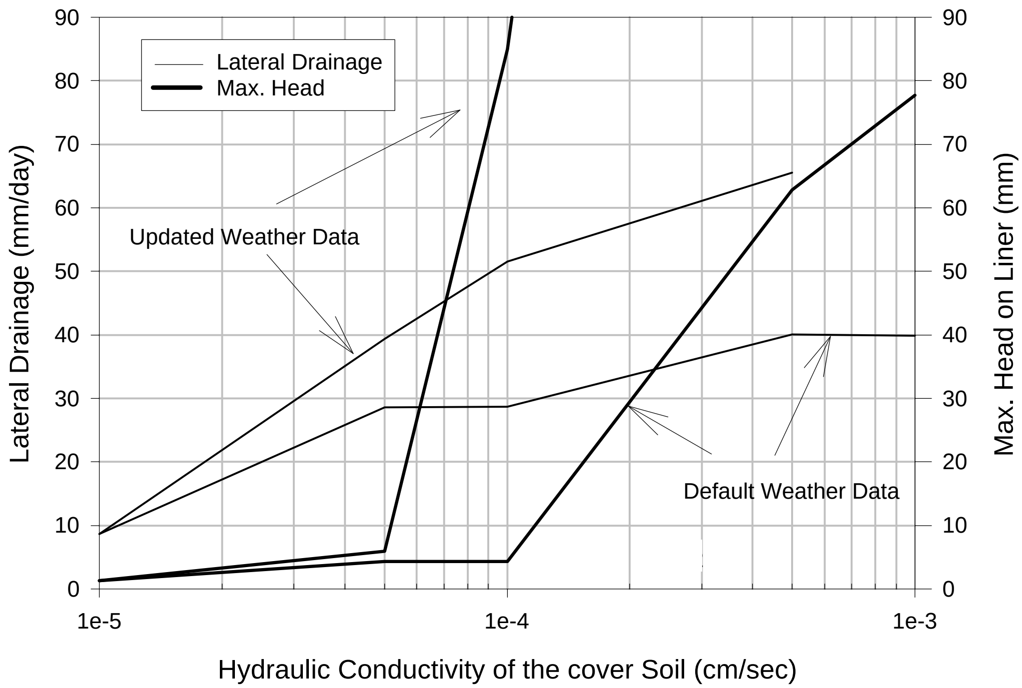

Figure 5: Effect of Cover Soil Hydraulic Conductivity on Lateral Drainage and Maximum Head, Default and Updated Precipitation Data, GC1, Slope: 3%

DESIGN EXAMPLE

A simple example for designing a drainage geocomposite system is presented utilizing the above discussed parametric study;

Given:

- Slope 3% with horizontal length of 40 m
- Cover soil is 45 cm thick, hydraulic conductivity: 1×10^{-4} cm/sec

Required:

- Ultimate Transmissivity of the drainage geocomposite

Solution:

- From Figure 5, at a hydraulic conductivity of 1×10^{-4} cm/sec, and considering the updated weather data, the head on the liner is approximately 85 mm. This exceeds the geocomposite thickness and indicates that the default geocomposite GC1 (thickness 5 mm, hydraulic conductivity of 10 cm/sec) is not adequate to provide the required flow capacity.

- Another simulation has to be run, this time using GC2 (thickness 7.5 mm, hydraulic conductivity of 50 cm/sec). The resulting maximum head is 1.58 mm and the lateral drainage is 51.73 mm/day. The results indicate that the design properties of the selected drainage geocomposite are adequate. However, since the resulting maximum head is less than the thickness of the geocomposite, another trial may be considered this time with less thickness and/or lower hydraulic conductivity. These trials should be run until a reasonable convergence occurs between the thickness of the geocomposite and the maximum head.

- A quick hand calculation could be done to verify the above results by calculating the required design Transmissivity (thickness x hydraulic conductivity) of the current slope configuration using the unit gradient design, Richardson and Zhao 1999:

$$\text{Transmissivity}_{\text{required}} = \text{Slope Length x Hydraulic Conductivity}_{\text{cover soil}} / \text{Gradient}$$
$$= (4000 \text{ cm}) \times (1\text{x}10^{-4} \text{ cm/sec}) / (0.03) = 13.33 \text{ cm}^2/\text{sec}$$

  For example, if a geocomposite has a hydraulic conductivity of 50 cm/sec, the required thickness is 13.33/ 50 = 0.27 cm or 2.7 mm. The difference between this thickness and the maximum head calculated by the HELP model (1.58 mm), is due to the fact that only 51.73 mm/day ($6\text{x}10^{-5}$ cm/sec) was considered as an impingement rate. This indicates an unsaturated condition of the cover soil. The hand calculations account for the worst case scenario where the cover soil is fully saturated.

- Applying the design by function approach, a safety factor of 8 (including the overall safety factor and the reduction factors) as suggested by Richardson and Zhao, 1999, is applied on the required design transmissivity to determine the ultimate required transmissivity from the manufacturer (8 x 13.33 = 106.64 cm^2/sec or $1.07\text{x}10^{-2}$ m^2/sec). This transmissivity value has to be verified in the laboratory at the anticipated field conditions as explained before, i.e., at soil boundary conditions, gradient of 0.03 (or preferably 0.1 for less testing variability), a normal stress of 50 kPa (typical for landfill closure systems), and a seating period of 100 hours or until the material stabilizes under the load whichever is less.

SUMMARY AND CONCLUSIONS

The HELP model is a useful tool for the hydraulic evaluation of the required flow capacity of the drainage layers in landfill systems. However, the output results should be properly interpreted, and carefully considered. The main limitation of the program is the precipitation data being handled on a daily average basis which results in an underestimation of the maximum head over the liner. Quick hand calculations, using the unit gradient method, could be done to verify the results, as explained above in the design example. The parametric study conducted in this paper showed the following main results:

1) The “Daily Peak” summary table in the HELP model should be considered to obtain the results of both the maximum head and amount of lateral drainage. No water- balance calculation should be conducted by subtracting the “Runoff” value from the “Precipitation” value as presented in this table because the data don't necessarily correspond to a particular day.

2) McEnroe’s equation gives an accurate estimate of the maximum head on the liner beneath the geocomposite drainage layer as long as the head is kept within the thickness of the geocomposite.

3) The weight-averaged hydraulic conductivity, as estimated in the HELP model, may significantly underestimate the maximum head on the liner beneath a geocomposite lateral drainage system.

4) For all practical purposes, it could be assumed that the cover soil will be saturated if the lateral drainage flow capacity is exceeded and the maximum head on the liner exceeds the thickness of the geocomposite.

5) Updated weather data could be utilized in the HELP model to give a more accurate representation of the current precipitation patterns which are more critical than the default ones.

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